Machine Learning Analysis of Hydraulic Fracturing Operations and Susceptibility to Induced Seismicity – Duvernay Formation

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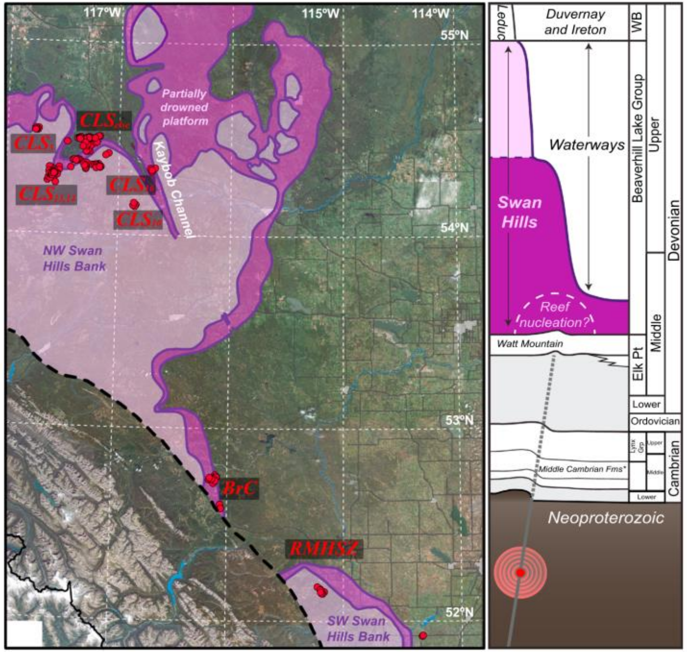
Outline

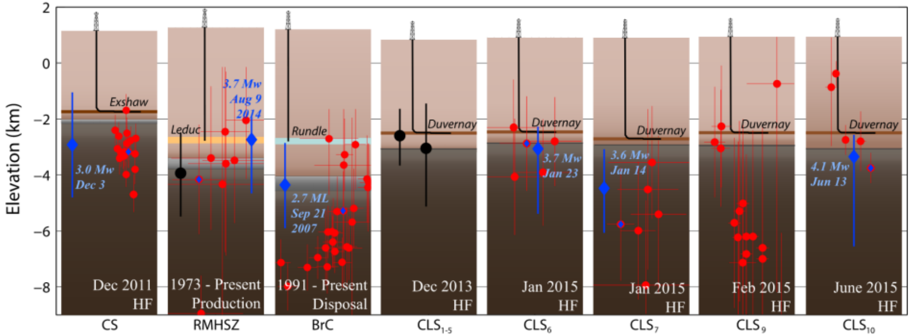
- Background
- Objectives and Scope
- Engineering and Geoscience datasets
- Data transformations and ML modelling
- Insights
- Summary & Next Steps

Background

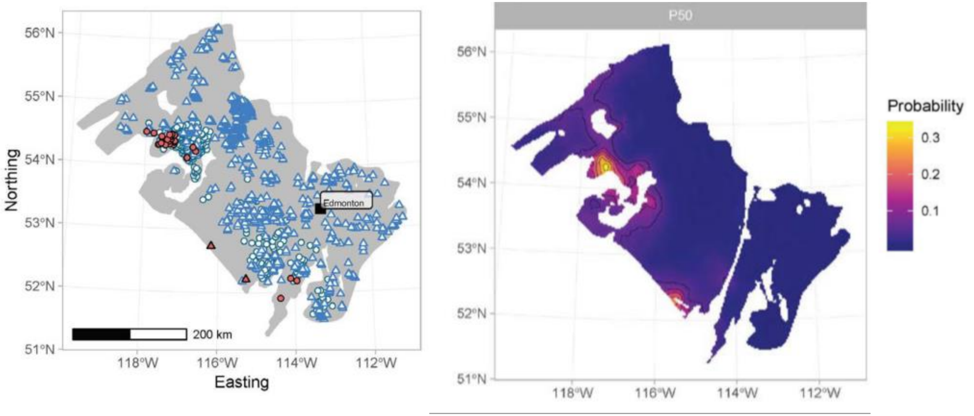
Reef nucleation hypothesis (Schultz et al., 2016, GRL)



Earthquake focal depths – constrained to Palaeozoic and Basement



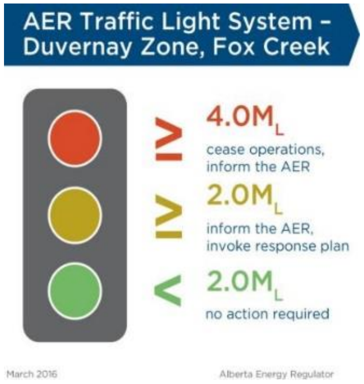
Geological susceptibility (Pawley et al., 2018, GRL)

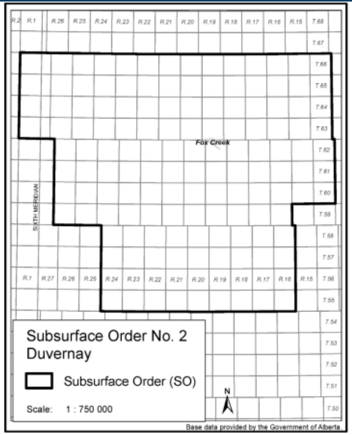


Objective and Scope

- **Objective** – Examine relationships between subsurface geologic conditions and operational parameters that result in induced seismic (IS) events

- **Study area** – Subsurface order #2: incorporate all induced seismicity data received through regular reporting channels, all operational hydraulic fracturing operation data in AER databases; including tour reports, service company frac reports & D59 submissions





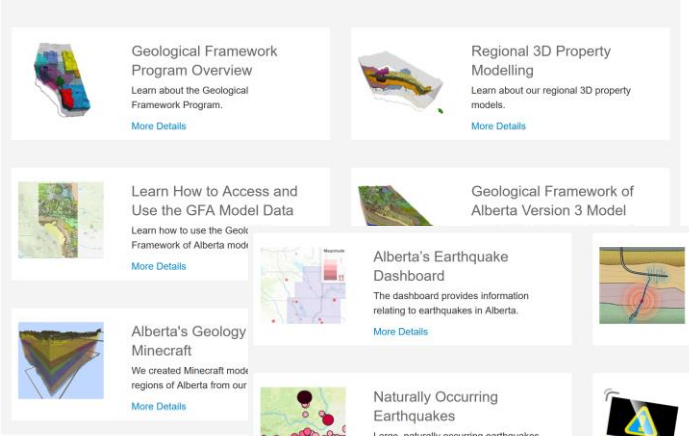
- Traffic Light Protocol (TLP) implemented for oil and gas operations specifically targeting the Duvernay Formation in the Fox Creek

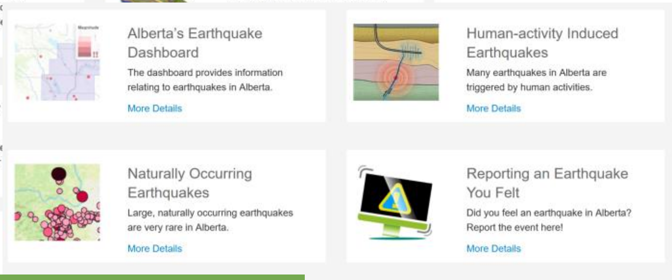
- Mandated assessment of hazards, monitoring, reporting, and a ***planned response to set magnitude*** thresholds

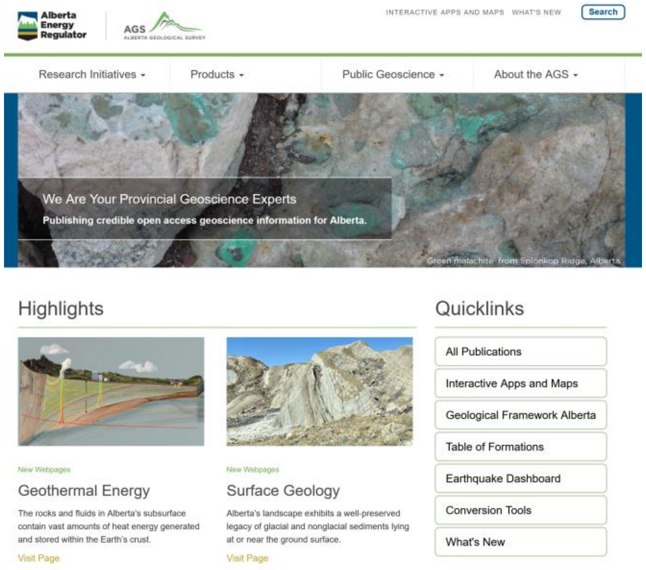
Role of the AGS

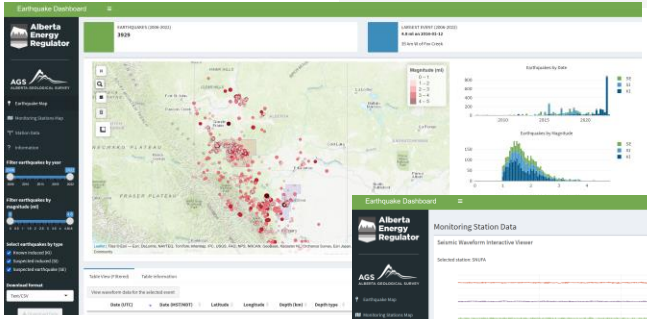
Providing the most relevant and up-to-date geoscience information and advice in formats readily accessible to government, industry, and the public

Geological modelling









Shiny from R Studio

Seismic monitoring and hazard mapping

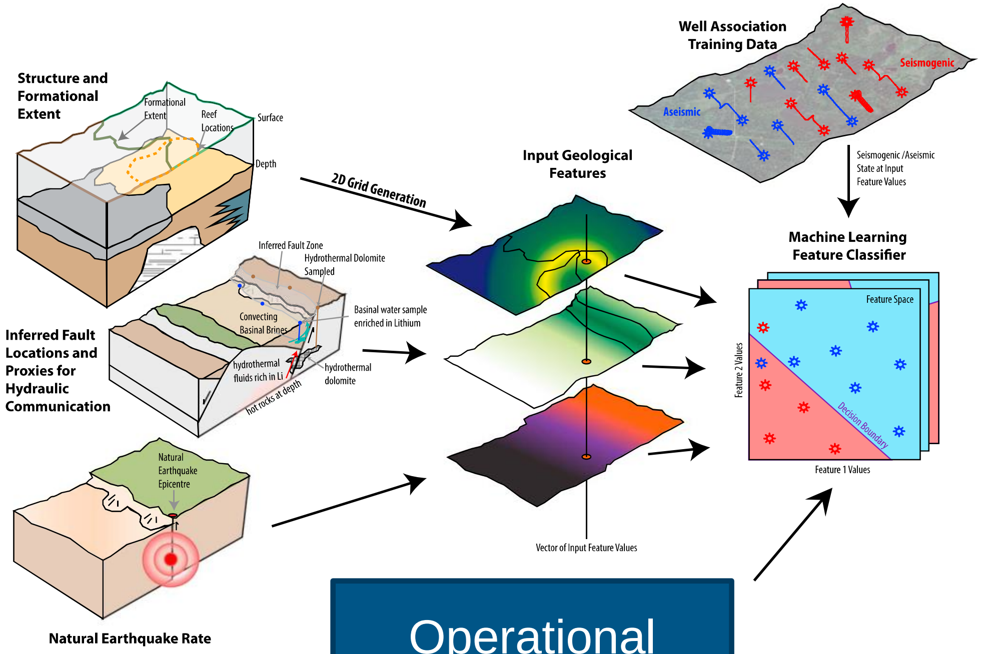
Potential Benefits

In addition to understanding the influencing hydraulic fracturing operational parameters and co-dependencies of geological conditions; this model:

- Model predictions, if validated, may be used as a guide to minimize the incidence of induced seismic events
- Deeper understanding of key variables may be applied to disposal / injection applications
- Potentially extrapolate / apply similar approach to other areas/activities

Modelling Approach

- **Spatio-temporal association**
  - HF wells with neighbouring seismicity < 5 km
  - Earthquakes fall within 3 month time window of pad operations
- **Seismogenic state** (classification approach)
- **Earthquake cluster maximum magnitude** (regression approach)

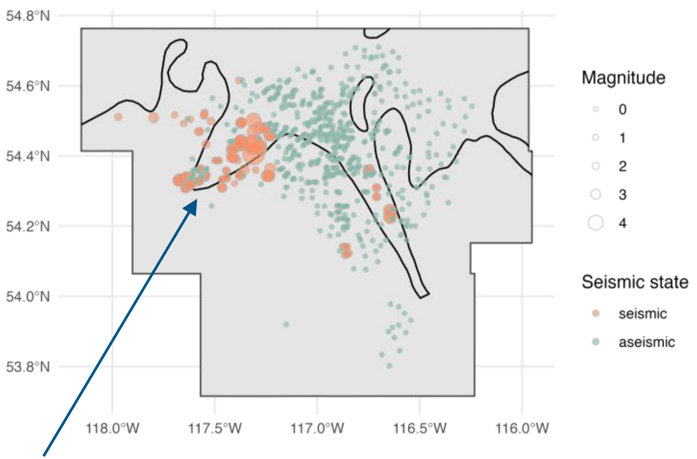


Operational parameters

Geological Factors

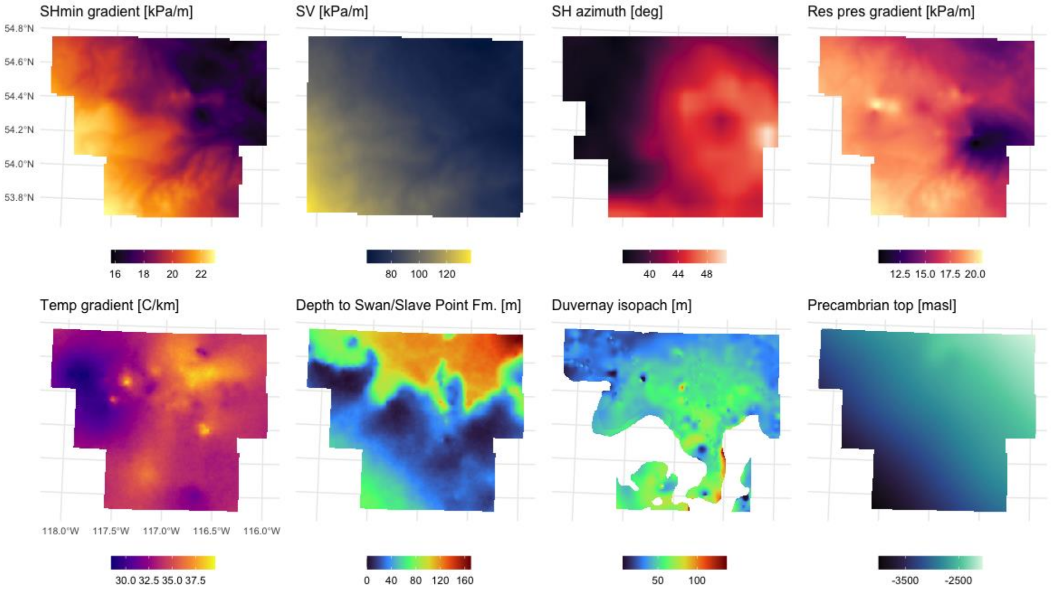
- Geological surfaces from the geological framework of Alberta
- Regional stress data from Shen et al. (2018)

Spatio-temporal association of earthquakes to well pads



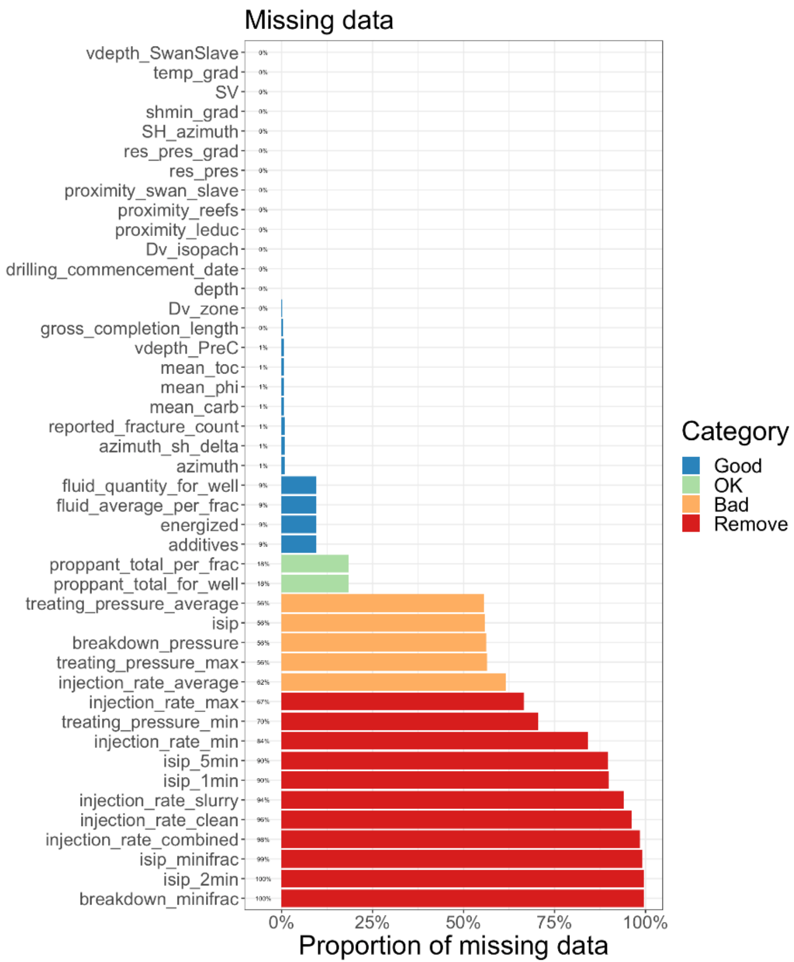
Upper Swan reef edges (distance measures)

Geological predictors

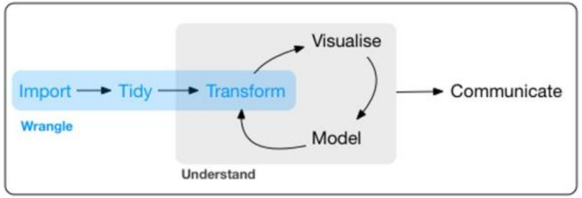


Operational Factors

- ~ 800 wells used in SSO2 (2010 - 2021)
- Carrier fluid volumes, proppants, additives from D59 submissions
- Breakdown and treating pressure, injection rates, ISIP from tour/frac reports
- > 30 different operational factors
- Large amount of missing data from partial digitization and differences in reporting
- Missing data imputed by semi-automated methods based on k-nearest neighbours



Transformations



Additives raw data

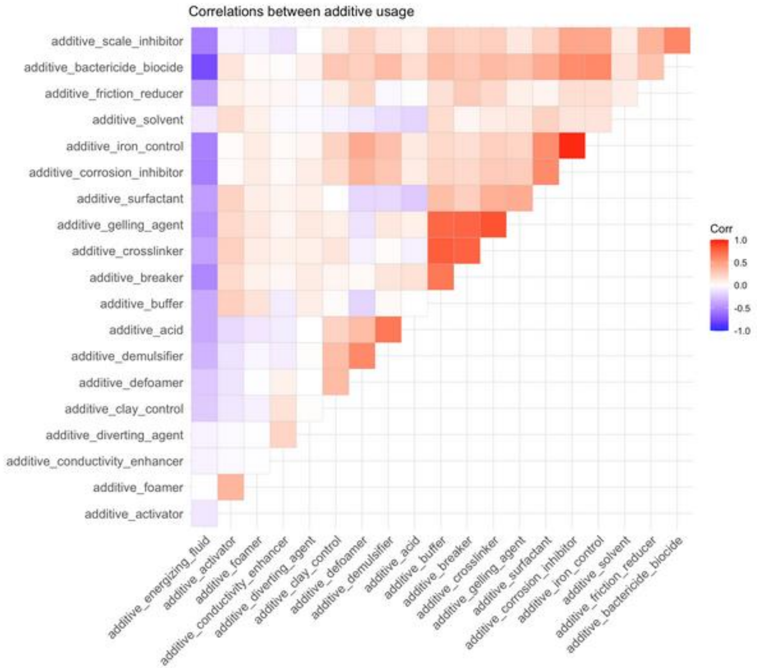
	component_supplier_name	component_trade_name	component_quantity_uom	additive_purpose
1	BJ Services	Hydrochloric Acid 15%	kg	Acid
2	BJ Services	Hydrochloric Acid 28%	kg	Acid
3	BJ Services			
4	BJ Services			
5	Step Energy Se			
6	Trican			
7	Step Energy Se			
8	Step Energy Se			

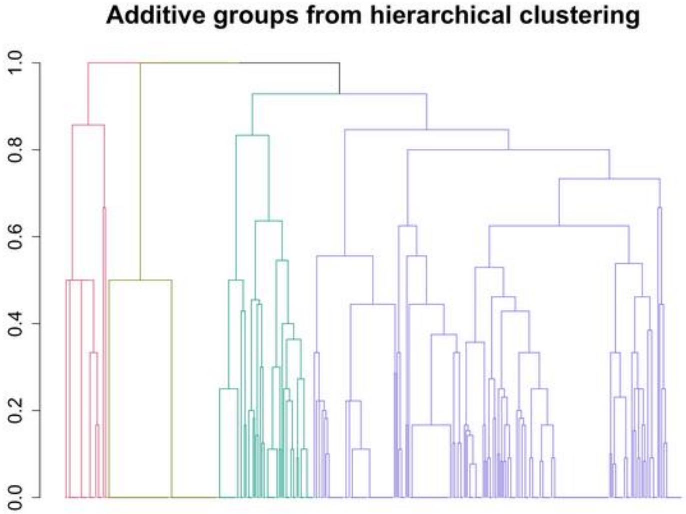
One-hot encoded

	uwi	additive_crosslinker	additive_surfactant	additive_activator	additive_gelling_agent	additive_corrosion_inhibitor	additi
1	100/01-01-060-18W5/00						
2	100/01-01-063-20W5/00	1	1	0	1	1	
3	100/01-04-062-24W5/00	0	0	0	0	0	
4	100/01-07-064-20W5/02	1	1	0	1	1	
5	100/01-09-062-24W5/00	0	0	0	0	0	
6	100/01-11-062-20W5/00	1	0	0	1	1	

Previous 1 2 3 4 5 … 78 Next

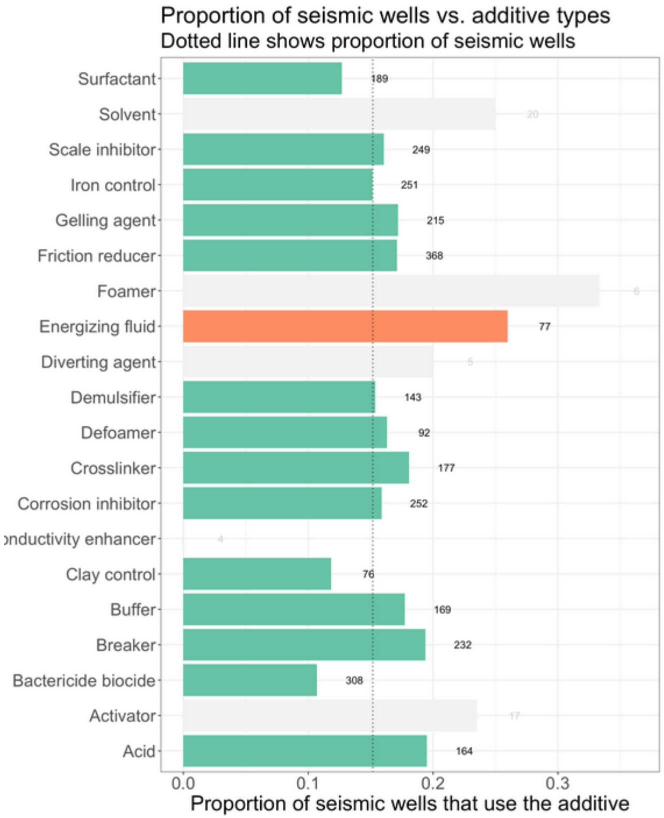
Transformations

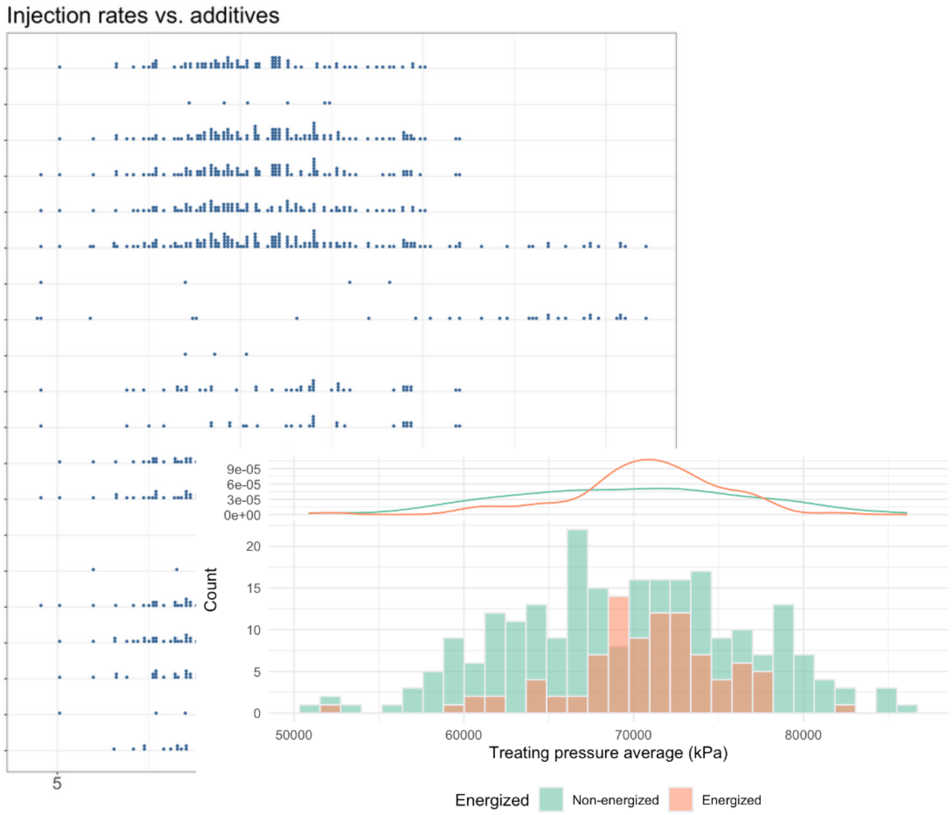




Groups: **(1)** viscosity altering agents (gelling, crosslinkers, breakers); **(2)** energized fluids; **(3)** acids/rust prevention (iron/corrosion control); **(4)** viscosity altering agents with acids

Exploratory Analysis

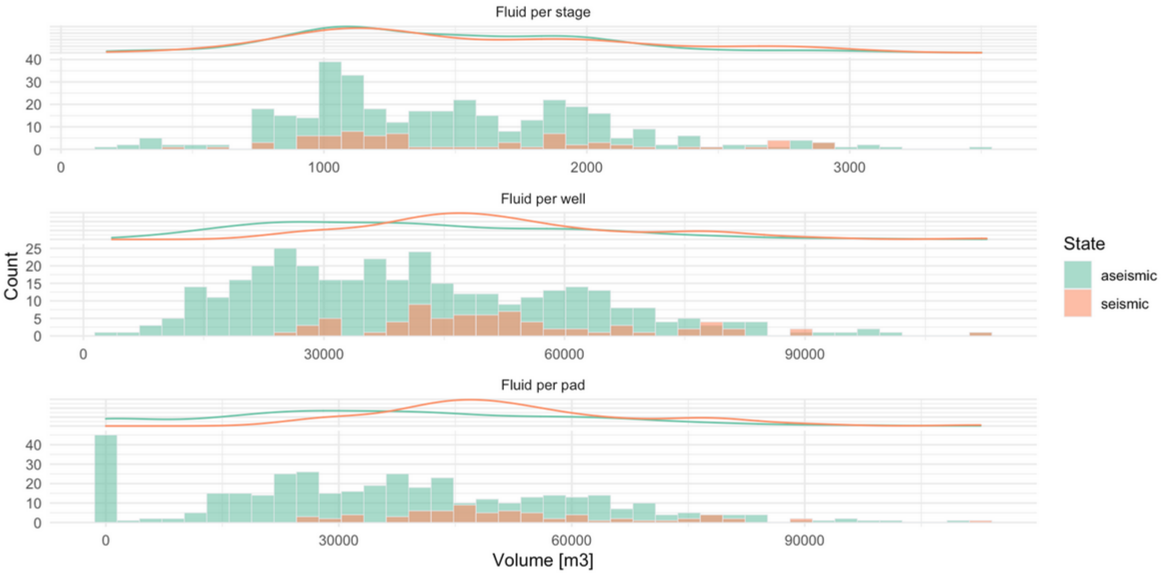




Exploratory Analysis

Fluid volumes, rates, pressures

Fluid volumes | Injection rates | Pressures | Proppants



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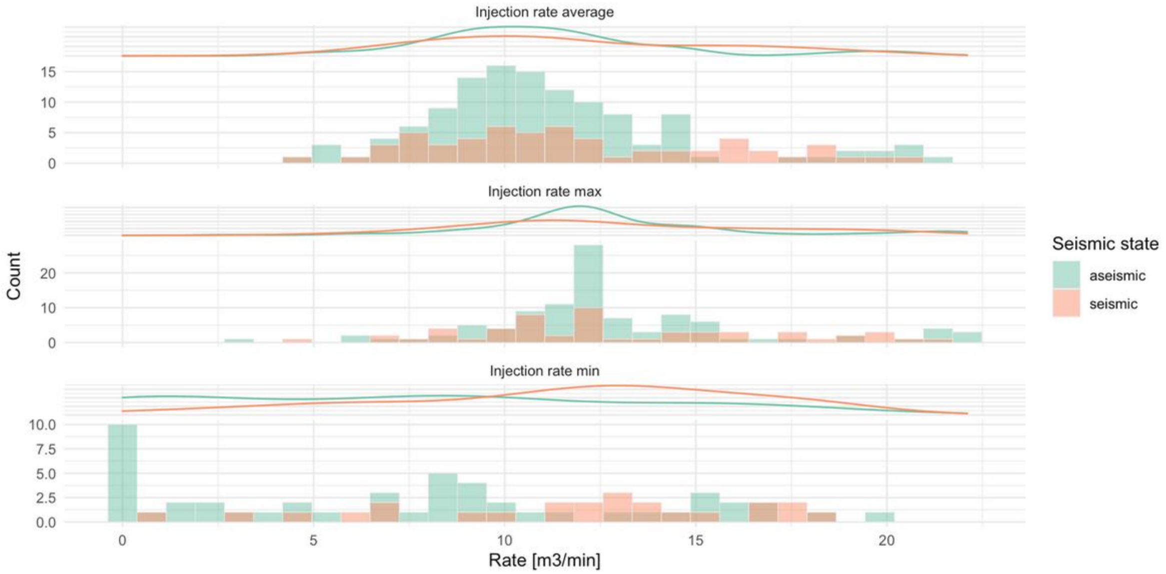

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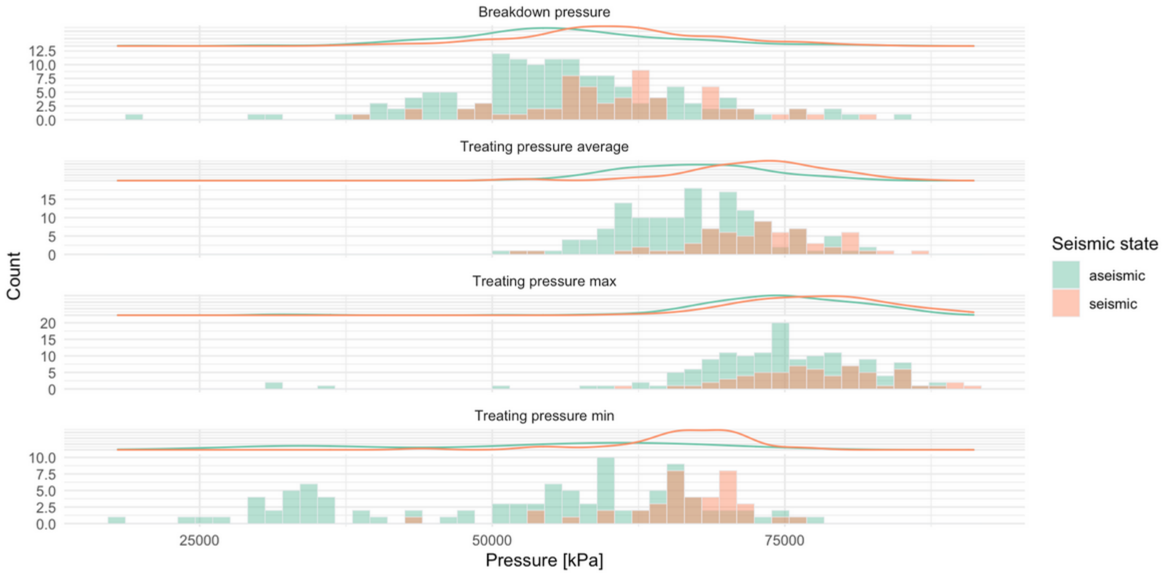

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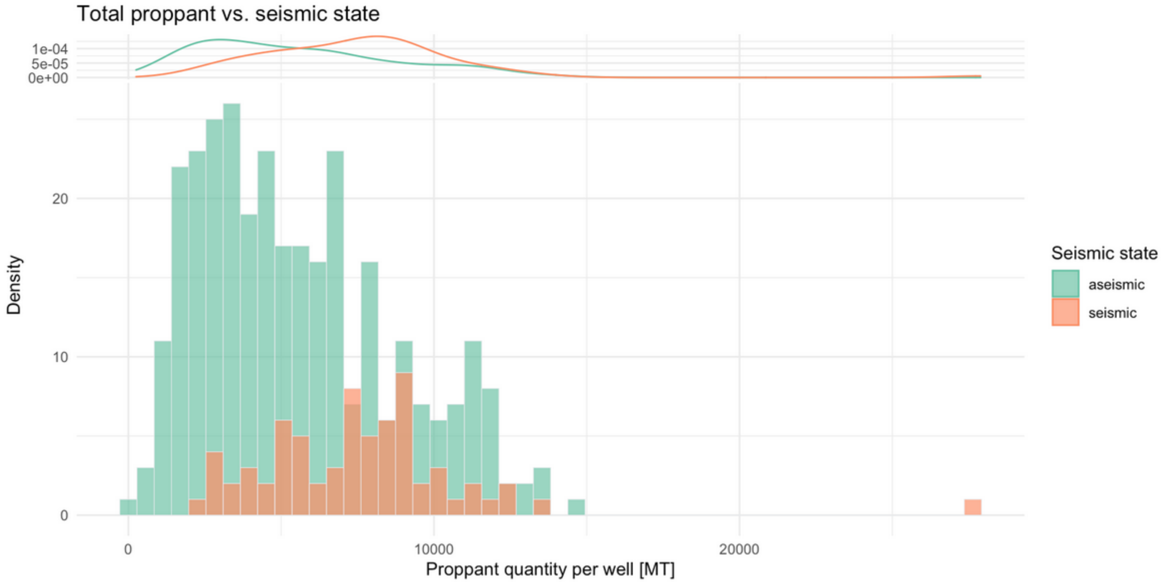
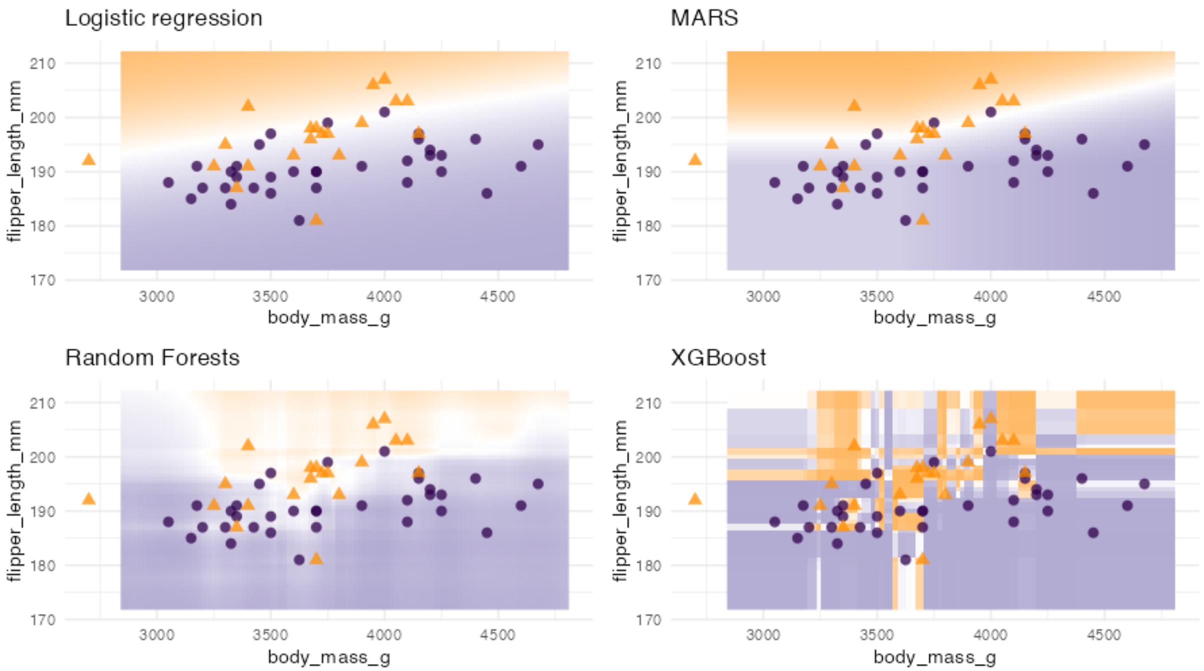


Feature Engineering

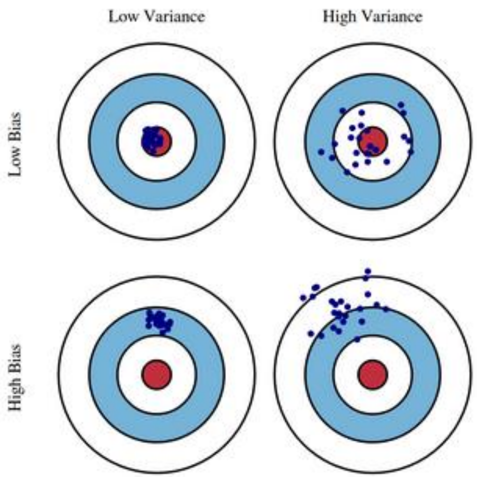
- Additives aggregated into groups
- Use of energizing fluids
- Proppant usage by size (also examined type)
- Total proppant usage (by well and per stage)
- Well bottom elevation - Precambrian top (depth to basement)
- Well bore azimuth difference from SH max azimuth
- Number of wells on pad
- Total fluids per pad

Evaluated Models

Example decision boundaries from different ML models

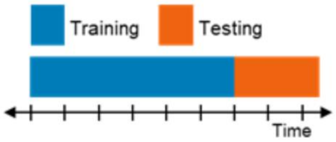


Bias-variance trade-off

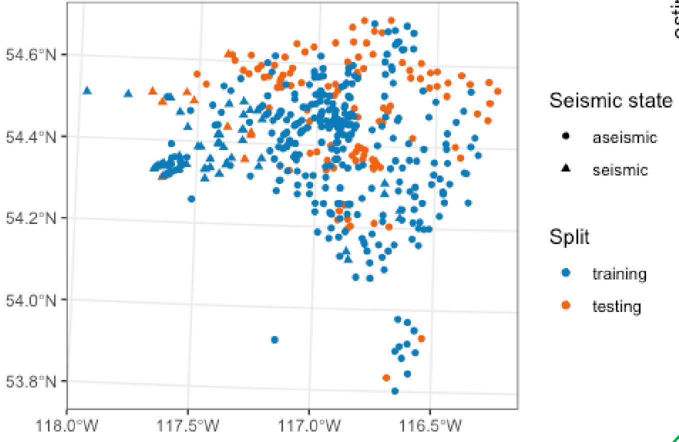


Model Evaluation Approach

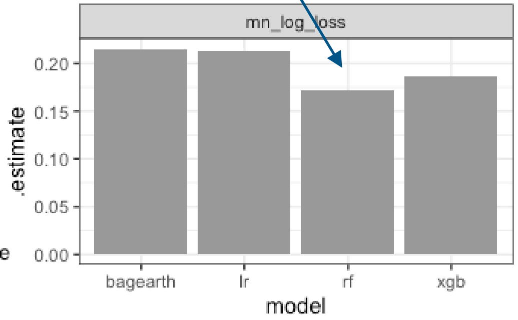
Time-based Estimation

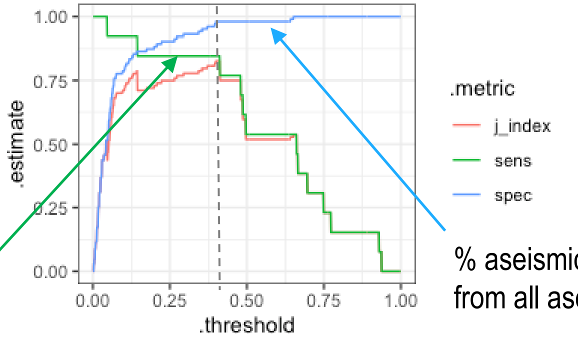


2010 - 2018 2018 - 2021



Random forest model with lowest error (log loss)

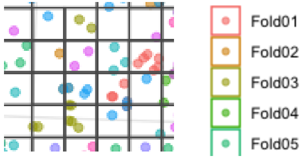


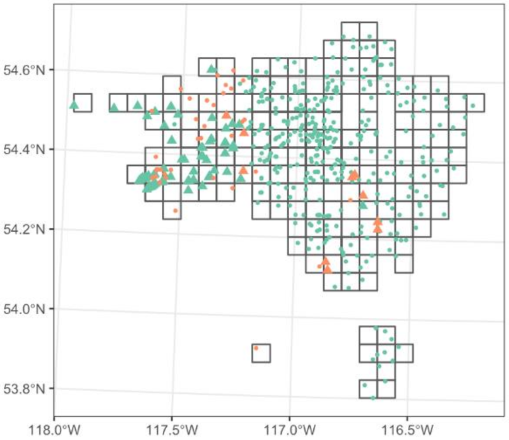


% seismic cases predicted from all seismic cases

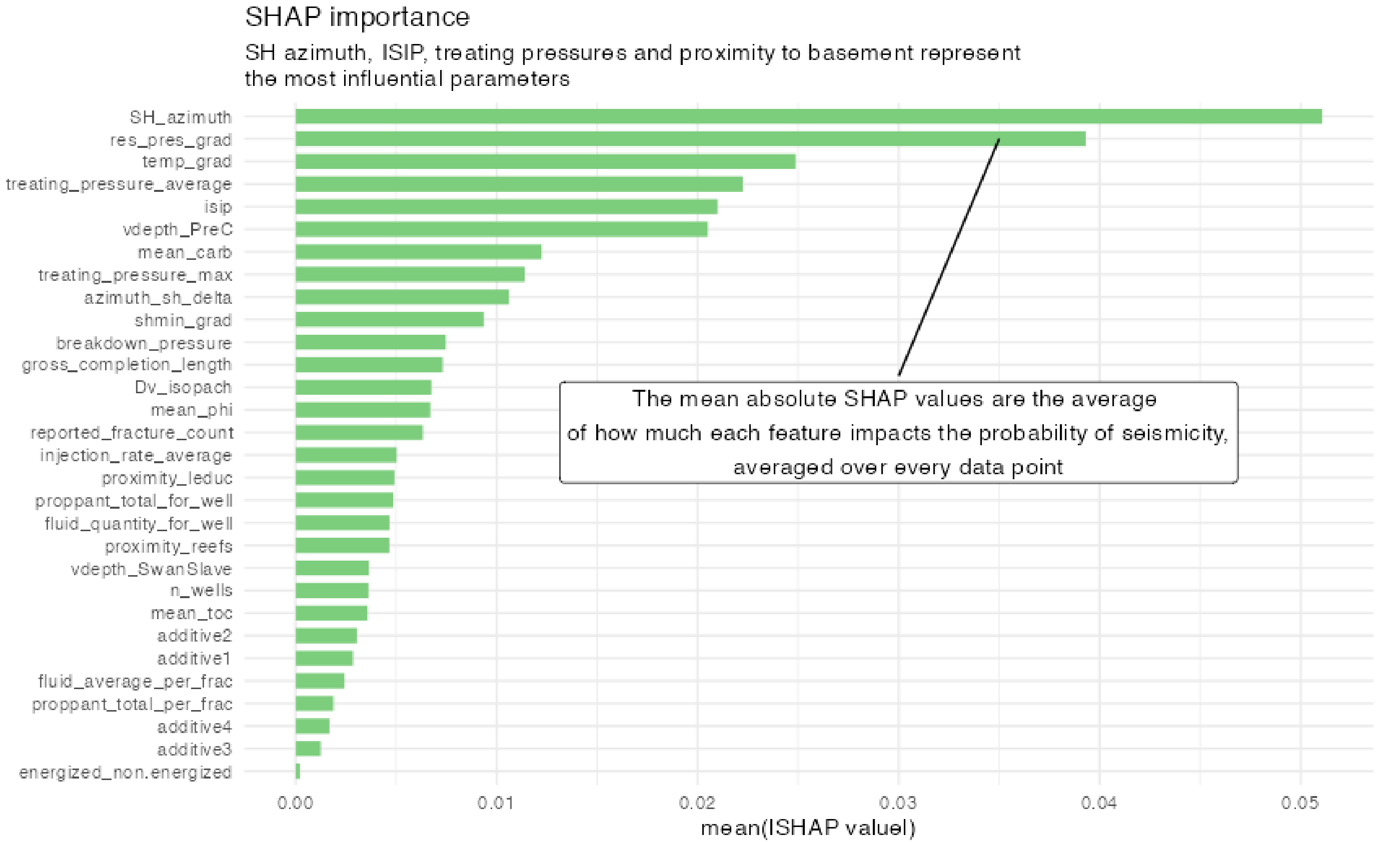
% aseismic cases predicted from all aseismic cases

Spatial-based Estimation





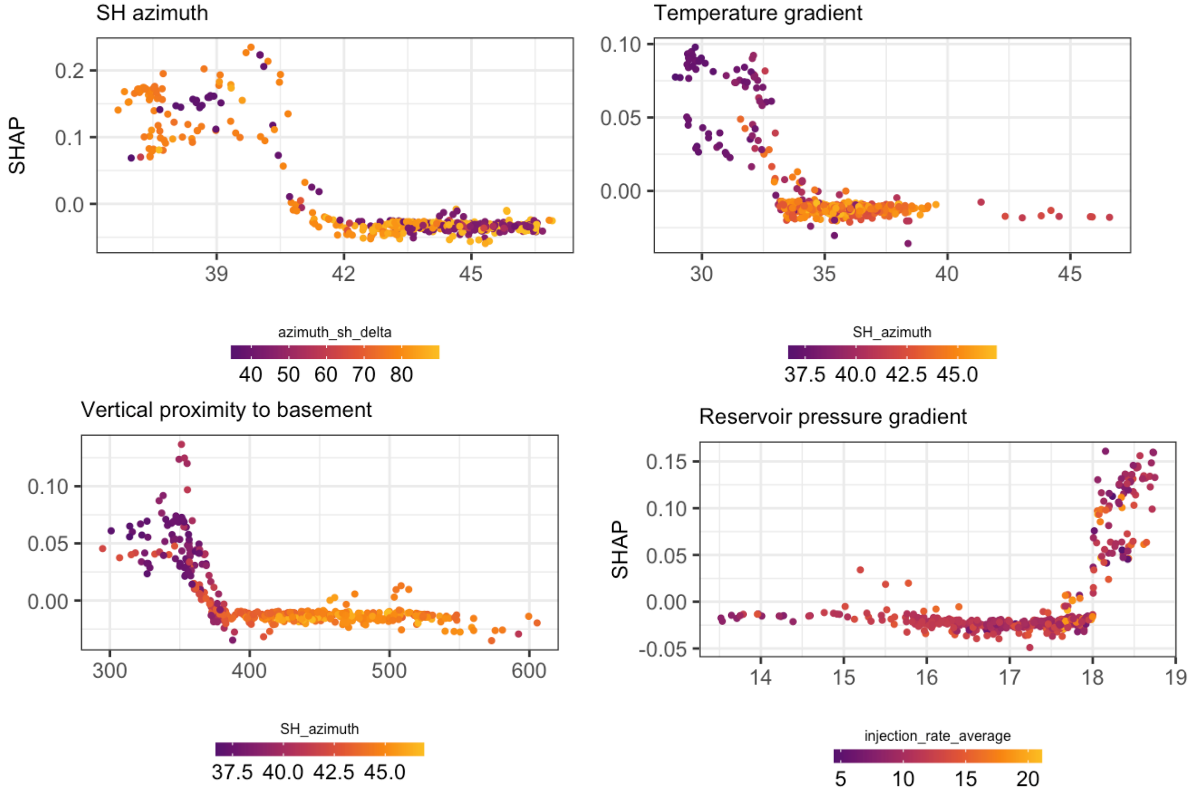
Model Explanations - SHAP



Geological features that act as **proxies structurally influenced areas** (SH azimuth, vertical depth to basement, temperature gradient) are important, with **reservoir pressure and treating pressure**.

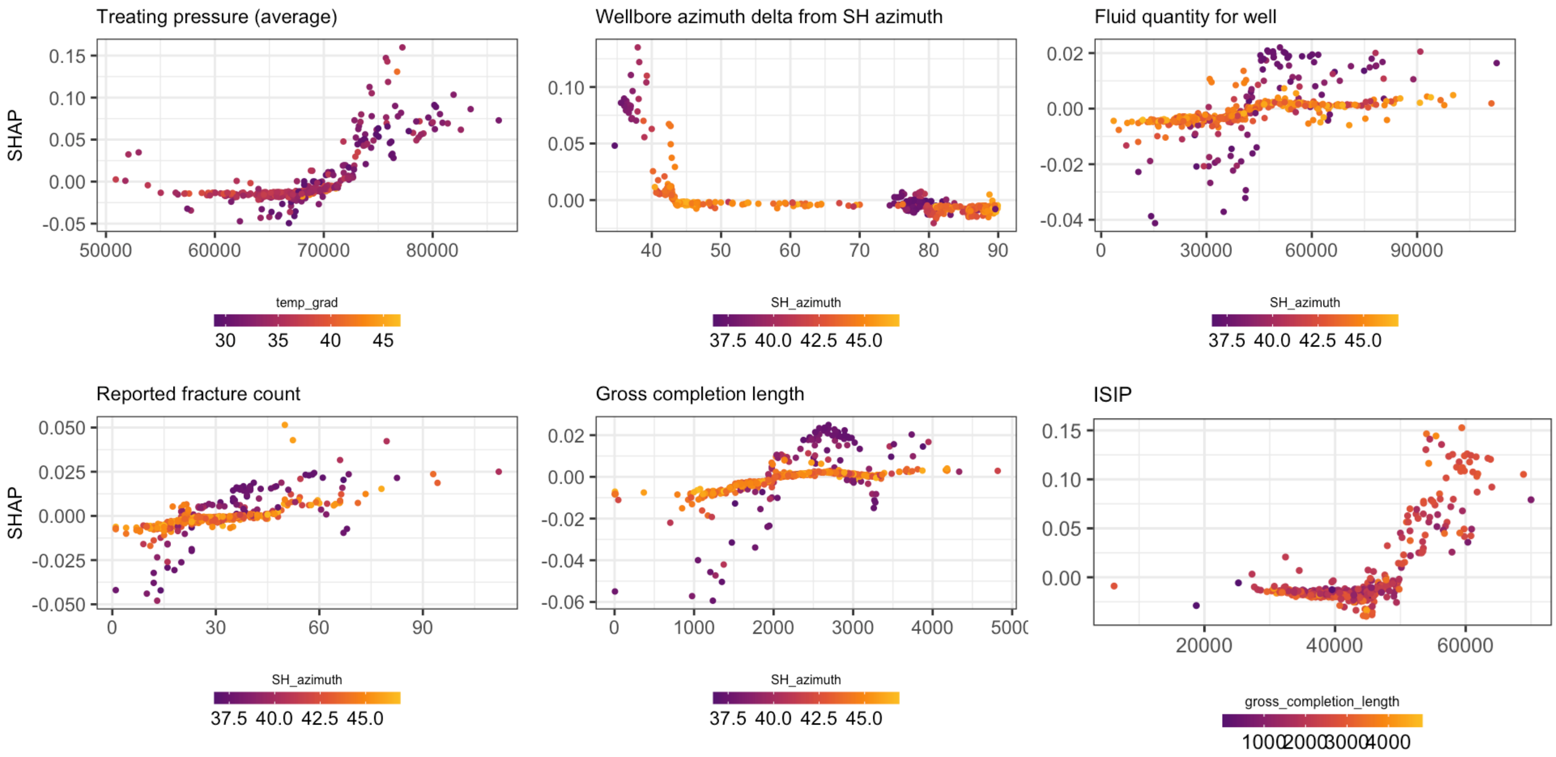
SHAP Feature Dependencies

Geological proxies and correlated variables



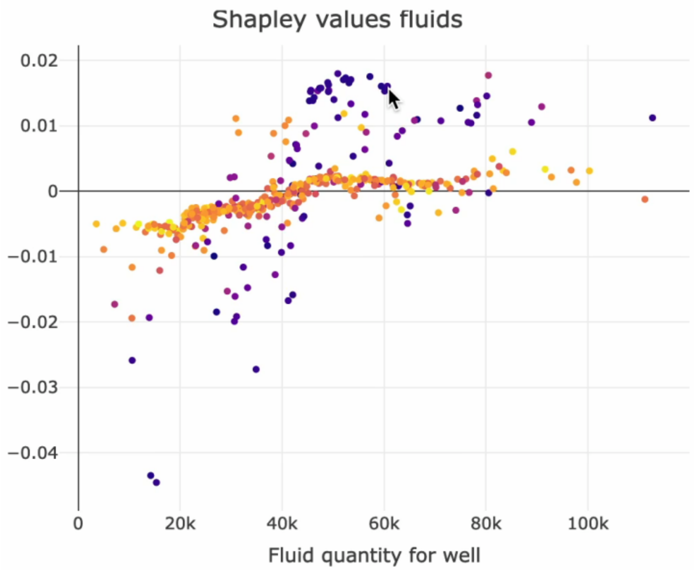
SHAP Feature Dependencies

Operational factors



SHAP – Geological Context

High fluid volumes only relevant in geologically-susceptible areas

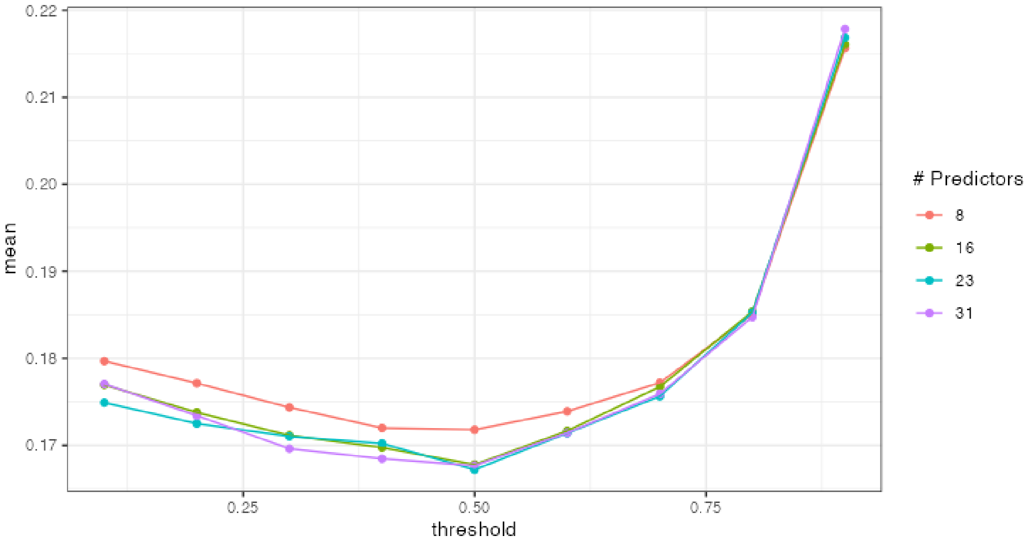


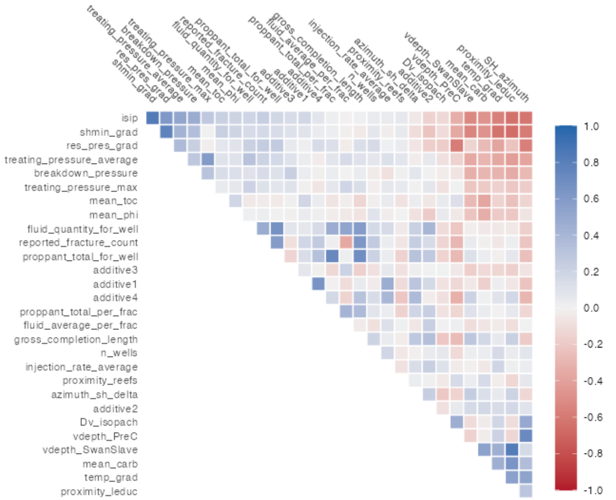
The fluid volumes that result in the highest IS estimates relate to observations that have both high volumes and are located in geologically-susceptible zones

Feature Selection

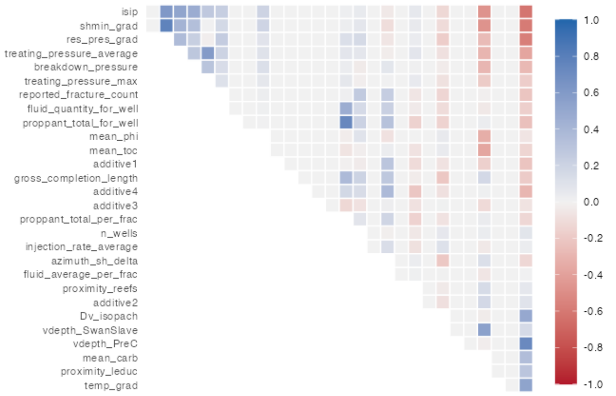
MRMR – Maximum Relevance and Minimum Redundancy

Features selected based on those that have the maximum correlation with the target variable, and the minimum correlation with other selected features

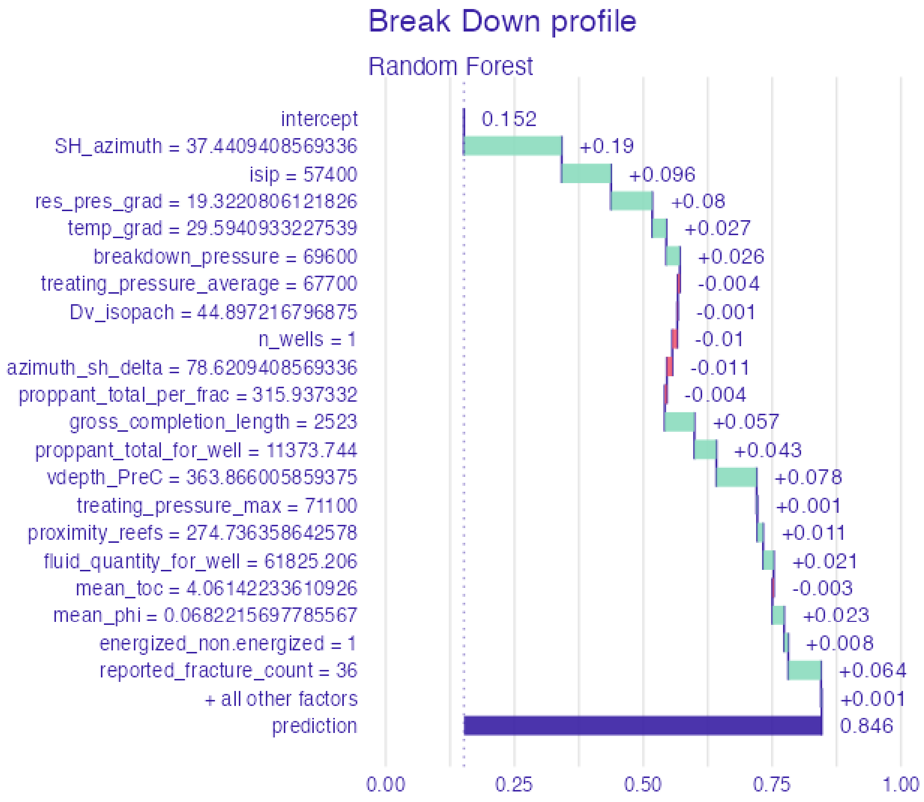


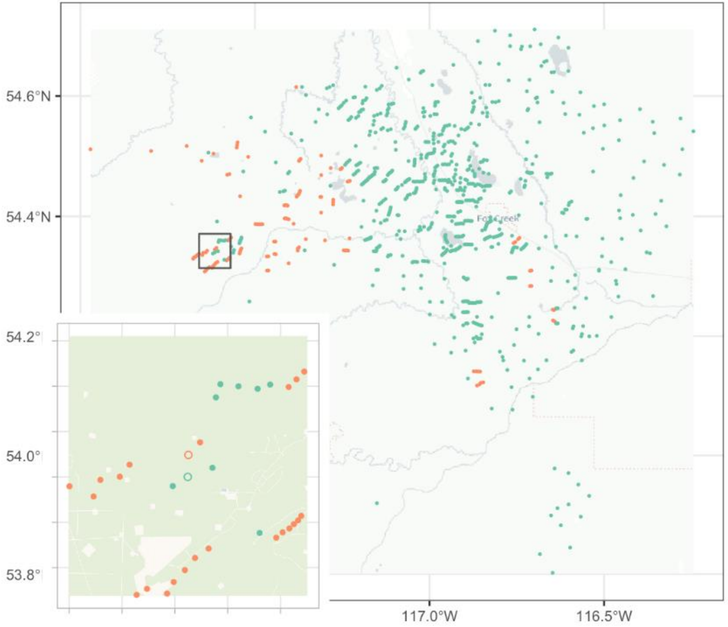


Greater sparsity after MRMR



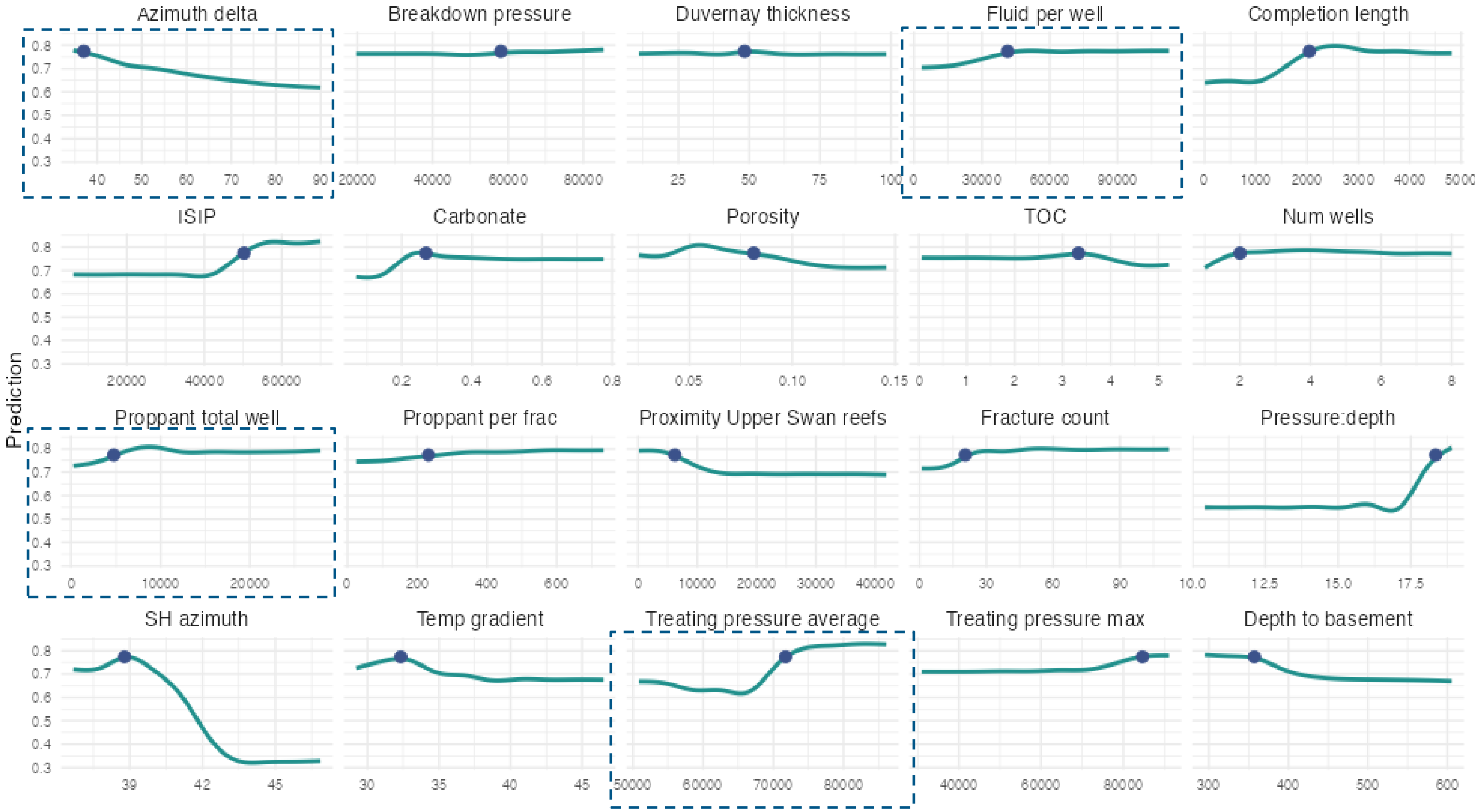
Local Test Cases





Example - two pad locations (aseismic and seismic) held out from the model

How could the model be used?



Ceteris Paribus Profiles

“All other things being equal”

Method to show how the model predictions vary around a single data point

Summary & Next Steps

- Results indicate ***that HF operational parameters broadly influence susceptibility to seismic activity***
  - ***Treating pressure***: A new finding; previous work focused on fluid volumes
  - ***Geology:*** Several geological parameters act as proxies for structurally-influenced / susceptible areas – modelling reveals interplay with several operational parameters

- Next steps:
  - Finalize modelling and increase data completeness
  - Model monitoring - apply to future IS events and monitor performance

Acknowledgements

Additional AER staff that assisted in developing the model include:

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Krista Beavis, Mauricio Canales, Elwyn Galloway.

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Questions